DRAG REDUCTION IN MICROFLUIDIC

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ABSTRACT

Frictional force is an unavoidable problem in transportation in pipeline which will cause a great pressure drop in the pipeline. Currently, industries use pumps to maintain the pressure in the pipeline for transportation. In order to solve this problem, researchers were developing drag reduction technique using different types of materials to get an alternative for pumps. Drag reduction is a technique where a minute of amountof drag reduction additives, usually parts per million (ppm), is added into liquid which reduce the frictional drag greatly. However, researches are mostly done in macroscale where there will be a waste in reagent. In this experimental study, investigation the effect of variable concentration of nanopowders with different size of microchannels and different flow rate on drag reduction is carried out. The nanopowder (Bismuth (III) oxide, Iron (II,III) oxide, Silica and Titanium (IV) oxide) is dissolved in DI water and the fluid is pumped into microchannels with the width and depth of 50 µm, 100 µm and 200 µm respectively which is connected to pressure transmitter through syringe pump. Nanopowder is an effective drag reduction additive with the drag reduction up to more than 64%. It is believed that Iron (II, III) oxide is the most effective DRA.

ABSTRAK

Daya geseran adalah masalah yang tidak dapat dielakkan dalam pengangkutan dalam perancangan yang akan menyebabkan penurunan tekanan besar dalam perancangan. Kini, industri menggunakan pam untuk mengekalkan tekanan dalam perancangan untuk pengangkutan. Penyelidik telah membangunkan teknik pengurangan seretan menggunakan pelbagai jenis bahan untuk mendapatkan alternatif untuk pam. Pengurangan seretan adalah satu teknik di mana sedikit jumlah bahan pengurangan seretan, biasanya bahagian per juta (ppm), ditambah ke dalam cecair yang memberi impak yang besar kepada pengurangan seretan. Walau bagaimanapun, kebanyakan kajian dijalankan dalam sistem makro yang akan menghasilkan banyak bahan buangan. Dalam kajian eksperimen ini, penyiasatan kesan kepekatan *nanopowders* dengan saiz *microchannels* dan kadar aliran pada pengurangan seretan dijalankan. *Nanopowder* ini (Bismut (III) oksida, Ferum (II, III) oksida, Silika dan Titanium (IV) oksida) dilarutkan dalam air DI dan cecair dipam ke dalam *microchannels* yang mempunyai dimensi 50µm, 100µm dan 200µm yang disambungkan kepada pemancar tekanan melalui pam picagari. *Nanopowder* adalah bahan pengurangan seretan yang berkesan dengan pengurangan seretan mencapai lebih daripada 64%. Ferum (II, III) oksida adalah dipercayai merupakan bahan pengurangan seretan yang paling berkesan.

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LIST OF ABBREVIATIONS

u	velocity
d	diameter
ΔP	Pressure drop
N_{Re}	Reynolds Number

Greek

ρ	density
μ	dynamic viscosity

Subscripts

a	after drag reducing additive addition
b	before drag reducing additive addition

LIST OF ABBREVIATIONS

DR	Drag reduction
DRA	Drag reduction additives
DRP	Drag reduction polymers
%DR	Drag reduction efficacy

1 INTRODUCTION

1.1 Motivation and statement of problem

With the development of economy around this world, energy resources are greatly utilized. The main energy resources in this world now are petroleum and natural gas. Transportation of petroleum and natural gas are essential to transport the natural resources from the upstream to downstream for refining. However, transportation of the petroleum and natural gas faces some problem such as frictional forces which causes great energy losses across the long pipelines.

In order to overcome the great energy losses across the pipelines, pumps are installed to increase back the pressure of the fluids in pipes. The installation of pump systems increase the utility cost in the term of purchase, installation and maintenance costs. Besides that, pumps also consumed large amount of energy that is electrical energy.

An alternative method has to be used to maintain the energy and pressure of the fluid and also reduce the utility cost and energy consumption. Since 1970, pipeline drag reduction (DR) technology has been developed to increase the bottom-line profit especially in oil and gas industry [1]. Toms was the first to publish DR data in 1949 where he reported the unusual low friction factor after adding poly(methyl methacrylate) in monochlorobenzene. This is later named as “Toms effect” [2]. Toms effect is commercially utilized in USA Alaskan pipeline to increase flow transportation efficiency and reduce drag which reported in 1982 [3].

However, lots of wastes are produced while doing these researches since large amount of reagents is used in the marcroscale researches. To overcome the problems, this work aims to do the research in microscale by using microfluidic devices. This can reduce the waste of chemicals and fluids which may cause hazard to the environment and even the health of living things. By using microfluidic devices, the time for the preparation of sample and measurement will be reduced greatly by up to two orders of magnitude [4].

In addition, different types of nanopowders are chosen to be used in this research to investigate the relationship of molecular weight, size and concentration of additives to drag reduction. Effect of the flow rate and the channel size of microchannel on the drag reduction also will be investigated.

1.2 Objectives

The following are the objectives of this research:

- To investigate the addition of nanopowder on the DR performance using microfluidic devices
- To investigate the effect of molecular weight, size and concentration of nanopowder on the DR performance.
- To investigate the flow rate of the solution and channel size of microchannels on the DR performance.

1.3 Scope of this research

The following are the scope of this research:

i) Experimental study using microfluidic technique

ii) Experimental study on DR performances using different types of nanopowder

iii) Experimental study on DR performances varying concentration, flow rate and channel size

1.4 Main contribution of this work

The following are the contributions:

i) understand the effect of different parameters on the DR performance

ii) enhanced DR hence reduce the cost in pumping system in chemical industries

1.5 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 provides a review of the DR researches done before. In this chapter also reviews on DR in microfluidic using different drag reduction additives (DRA's) such as polymers and surfactants.

Chapter 3 gives a description of the methodology of this research work including the chemicals and equipments use.

Chapter 4 presents the results of this experiment. In this chapter also presents the discussion for the results obtained from experimental work.

Chapter 5 draws together a summary of the thesis and outlines the future work which might be derived from the model developed in this work.

2 LITERATURE REVIEW

2.1 Introduction

Drag reduction (DR) is a technique where a minute of drag reducing additives (DRA's) are added, usually part per million (ppm) to reduce the energy losses along the flow [3]. Since 1970, pipeline drag reduction technology has been developed to increase the bottom-line profit especially in oil and gas industry [1]. Toms was the first to publish drag reduction data in 1949 where he reported the unusual low friction factor after adding poly(methyl methacrylate) in monochlorobenzene. This is later named as "Toms effect" [2]. Toms effect is commercially utilized in USA Alaskan pipeline to increase flow transportation efficiency and reduce drag which reported in 1982 [3, 5]. Since then, several types of drag reducing agents (DRA's) such as polymers [6-10] and surfactants [11-16] were introduced and tested for different industrial applications [17-21].

Conventionally, researches on DR are done in pipes where the time of preparation is long and the amount of reagents used is significant thus contribute to environmental problems. Recently, microfluidic was adopted as one of the economically feasible techniques in validating the DR effects of many new additives [22-24] to solve the problems caused by doing researches in pipes. Microfluidic is a technique to handle a small volume of fluid within the microfluidic devices, named microchannel. There are many advantages using microchannels especially in research field. These include only small amount of reagent are needed, reduce the waste hence is more environmental friendly, more precise in handling the fluid, accuracy and efficiency increases and more economic [22, 25, 26]. Besides application in DR, there is a wide range of application for microfluidic including chemistry and biological assay [27]. Functional elements such as mixers, reactors, sensors and separators in microfluidic have also developed [28]. Microfluidic devices have been used for the research on the smart drug delivery [29, 30] and used in medical diagnostic and biosensors [31]. The treatments now for cancer are surgery and radiation and chemotherapy which will kill healthy cells and cause toxicity to patient. In order to solve this problem, Paul Ehrlich proposed that drugs should be released at the affected area. A review published by I.U Khan et al about cancer targeted drug delivery systems by microfluidic suggested that drug delivery using microfluidics should be developed to synthesis drug carriers [32].

2.2 Drag Reduction in Microchannels

2.2.1 Soluble Additives

2.2.1.1 Polymeric Drag Reduction

Polymeric drag reduction is one of the methods of DR where a minute amount of polymer is added in the fluid [2, 6-10, 19, 33, 34]. By adding polymers, the energy from the turbulence of the flow is transferred to the polymers thus DR will happen [19]. It is believed that DR of up to 75% can be achieved by adding polymer [35]. There are also researches that show that the increase in the concentration of the polymer solution decreases the Reynolds stress more [36, 37]. The efficiency of DR also affected by many other factors other than the concentration of DRA. It is found that DR efficiency increases with the increase of temperature, drag reduction agents concentration, flow rate and pipe roughness with the decrease of pipe diameter [38].

Sun et al. used polyacrylamide-based polymer to investigate the DR in microchannel and it is observed that up to 50% of DR is achieved. Greater DR was contributed by higher concentration of polymeric DR at low velocities and large diameter of micro-channel. [39].

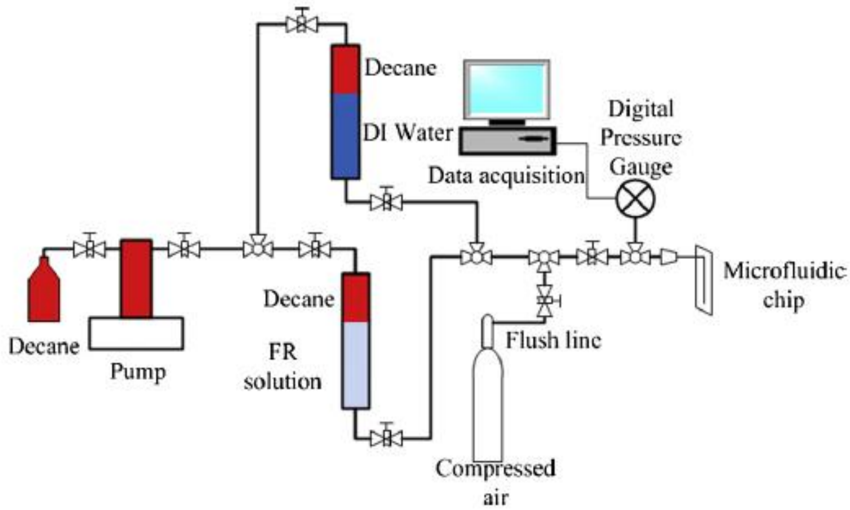

Figure 2-1: Schematic diagram of the experiment for DR using polyacrylamide-based polymer[39]

Tang et al. used polyacrylamide (PAM) solution in three types of different microchannels including fused silica, fused silica square and stainless steel microchannels to investigate the flow behaviours of non-Newtonian fluid. From the experiment, it can be observed that DR is greater in rough stainless steel microtubes than smooth fused silica microchannels [40].

2.2.1.2 Surfactant Drag Reduction

Surfactant, which produces wormlike micelles, also has the same effect like polymer drag reducing agents to enhance the DR. The strong vorticity fluctuation or formation of eddies near the wall disappears with the introduction of surfactant [12, 41, 42]. Surfactant is suitable for the use of lone-term re-circulating heating and cooling system since it has the ability to self-repair after mechanical degradation. Surfactants as the DR agents only receive great attention after the work of Dodge and Metzner [43]. Since then, there are more and more experimental work in this field has been published [11-16, 44, 45].

G. Xia et al. have done an experimental work using 100 ppm Sodium Dodecyl Sulphate (SDS with 95% purity grade) aqueous solution and 300 ppm Alkyl Polyglycoside (APG1214 with 98% purity grade) aqueous solution in a manifold microchannel to study the effect of surfactant on the pressure drop. It is found out that APG is a better surfactant compare to SDS where DR is dependent on the temperature and the velocity of the fluids [46].

A. Ushida et al. used polyethylene glycol (PEG) and surfactant solutions in the experimental study on the DR for the liquid-liquid flow through micro-orifices with the diameter ranging from 5 µm to 400 µm. It is found out that the viscosity of the solutions do not influence the DR. A greater DR is achieved for PEG8000 for 10 µm to 5 µm micro-orifices where DR is almost the same for PEG20000 and PEG8000 for the orifices diameter of 400 µm to 15 µm. In addition, it is found that non-ionic surfactant and cationic surfactant is more effective than anionic surfactants [47, 48].

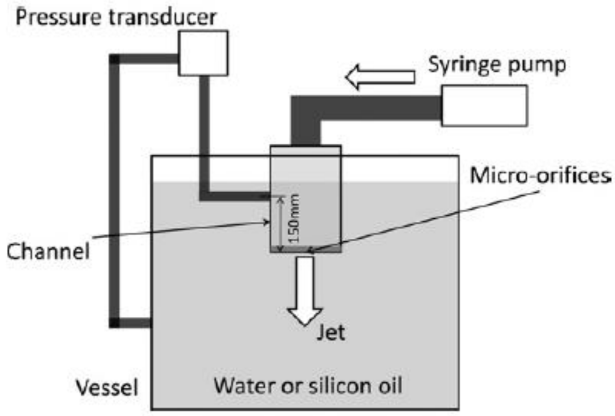

Figure 2-2: Experimental set up for measuring pressure drop for the experiment of DR using polymer and surfactants additives in liquid flow[47]

2.2.2 Insoluble Additives

2.2.2.1 Nanopowders

Nanofluids, containing nanoparticles suspended in base fluid normally water or organic liquids [49], play crucial role in most of the applications of practical interest [23, 50-52] due to its dispersion quality and stability. However, there is no study has been done on DR using nanoparticle in reducing pressure drop comparing to polymers and surfactants which have been done to an extent in both micro-channels and pipes.

2.3 Summary

With the results from those researches or experimental study, public especially for industrial area can understand more on the mechanism and the factors affecting the efficiency of DR. Thus, DR can be applied in the most optimum way. As from mentioned before, it can be clearly seen that there are no studies done on DR using nanopowders. Thus, in this research, experiment on DR using nanopowder as DRA is done in order to have more understanding on this system and thus can be applied in industries to decrease the dependence on pump system hence decrease the consumption cost besides reducing the turbulence and drag inside pipelines.

3 MATERIALS AND METHODS

3.1 Raw Materials

3.1.1 Transported Liquid

Deionised water which is obtained from the Chemical Engineering Laboratory of University Malaysia Pahang is used throughout this experiment.

3.1.2 Chemicals

Four types of nanopowders: Bismuth (III) oxide, Iron (II,III) oxide, Titanium (IV) oxide and Silicon dioxide are chosen for this experimental work, which are provided by Sigma Aldrich, considering the hazards of the chemicals. Non hazardous chemicals are chosen since they are more environmental friendly and will not cause harm to other living things. Besides that, size and molecular weight of nanopowders are taking into consideration. The four types of nanopowders chosen are as shown in Table 3-1:

Chemical	Molecular weight (g/mol)	Size(nm)	Density (g/mL)
Bismuth (III) oxide	465.96	90-210	0.5-1.1
Iron (II,III) oxide	251.53	50-100	4.8-5.1
Titanium(IV) oxide	79.87	<100	-
Silica	60.08	200-300	0.037

Table 3-1: The physical properties of nanopowder chosen

3.2 Nanopowder solution preparation

5 different concentration of each nanopowder solution were prepared ranging from 100ppm to 500ppm. Nanopowder solution was initially prepared at the concentration of 500ppm by adding deionised water which will be homogenised in a vortex at 500ml for a few seconds by magnetic stirrer. The solution was agitated on a moving table for 7 hours to achieve dispersion of the nanopowder without breaking the molecules. Before running experiment, the solution was then homogenised by magnetic stirrer at 100rpm for 2 hours. Dilutions were prepared from this solution by adding in deionised water and were stirred again for 2 hours at 100rpm[53].

3.3 Equipments

3.3.1 Microchannels

Different types of straight microchannels were used in this experiment to investigate the effect of size of microchannel on DR. Three topas straight microchannel with the width and depth of 50 µm, 100 µm and 200 µm respectively and length of 58.5mm were used.

3.3.2 Syringe Pump

Syringe pump (model: SN-50F6) was used to pump the solution from the syringe into the microchannel by controlling the flow rate of the solution.

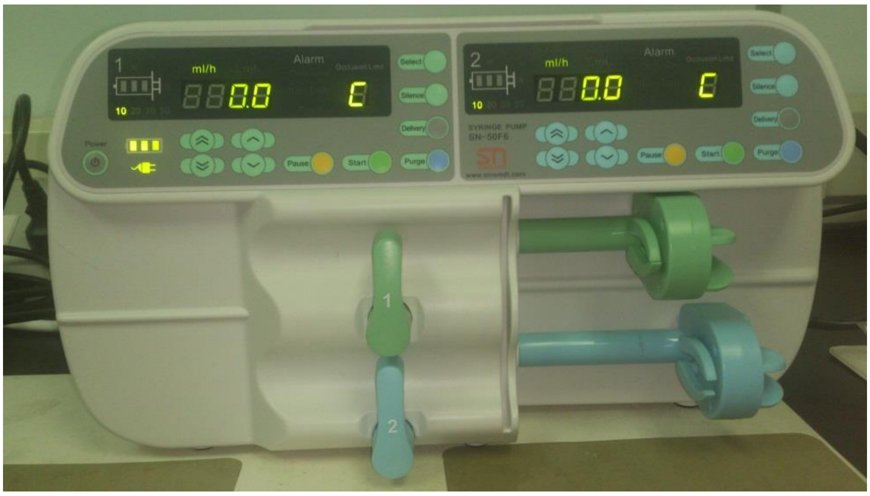

Figure 3-1: Syringe pump